CLAIMS

What is claimed is:

1. A system for automatically orienting a spherical object using a reference indicium on the spherical object, comprising:

means for automatically locating and defining a position and two-dimensional orientation of the reference indicium; and

means for automatically orienting the spherical object by sequentially rotating the spherical object from the defined position and two-dimensional orientation determined by the automatic locating means through predetermined angles so that the reference indicium of the spherical object has a predetermined final position and two-dimensional orientation wherein a target point on the spherical object, which has a predetermined spatial relationship to the reference indicium, is prepositioned for further processing.

2. The system of claim 1 wherein the automatic locating and defining means comprises:

first and second locating work stations, each of the first and second locating work stations having an axis of rotation and being operative to rotate the spherical object about the axis of rotation;

transposing means for conveying the spherical object between the first and second locating work stations in such manner that the spherical object is rotated through a single-degree of freedom by 90 degrees between the first and second locating work stations and between the second locating work station and the orienting means, respectively;

an imaging system operative to generate an image of the spherical object at each of the first and second locating work stations as the spherical object is rotated about the axis of rotation of the first and second locating work stations through at least one revolution, respectively; and

calculating means for processing the image of the spherical object generated at the first and second locating work stations, respectively, to locate and identify the defined position and two-dimensional orientation of the reference indicium and to determine the predetermined angles for rotation for the spherical object by the orienting means.

3. The system of claim 2 wherein

the calculating means is operative to process the image of the spherical object generated at the first locating work station to identify a coarse position and two dimension orientation of the reference indicium at the first locating work station and to determine an angle of rotation for the spherical object at the first locating station; and wherein

the first locating work station means is operative to rotate the spherical object about the predetermined angle to move the spherical object to a second position at the first locating work station; and wherein

the transposing means is then operative to convey the spherical object to the second locating work station wherein the spherical object is rotated through the single-degree of freedom by 90 degrees such that the reference indicium is at the defined position and two dimensional orientation on the equator of the spherical object at the second locating work station.

4. The system of claim 2 wherein the 90 degrees single-degree of freedom rotation provided by the transposing means between the first and second locating work stations and the second locating work station and the orienting means is coplanar with the axes of rotation of the first and second locating work stations.

5. The system of claim 2 wherein the imaging system comprises:

a first imaging means having an image axis perpendicular to the spherical object at the first locating work station;

a second imaging means having an image axis perpendicular to the spherical object at the second locating work station; and

wherein the first and second imaging means are operative to generate the image of the spherical object at the first and second locating work stations, respectively.

6. The system of claim 1 wherein the imaging system comprises:

a single imaging means;

a first set of mirrors aligned to capture the image of the spherical object at the first locating work station for the single imaging means; and

a second set of mirrors aligned to capture the image of the spherical object at the second locating work station for the single imaging means;

where the single imaging means is operative, using the first and second set of aligned mirrors, to generate the image of the spherical object at the first and second locating work stations, respectively.

7. The system of claim 1 wherein the automatic orienting means comprises:

first, second, and third orienting work stations, each having an axis of rotation and being operative to sequentially rotate the spherical object through one of the predetermined angles so that the reference indicium is transposed from the defined position and two-dimensional orientation at the first orienting work station to the predetermined final position and two-dimensional orientation at the third orienting work station wherein the target point on the spherical object is prepositioned for further processing; and

transposing means for conveying the spherical object between the first and second and second and third orienting work stations in such manner that the spherical object is rotated through the single-degree of freedom by 90 degrees between the first and second orienting work stations and between the second and third orienting work stations, respectively.

8. The system of claim 7 wherein the transposing means comprises:

a first transposing mechanism pivotally mounted intermediate the first and second orienting work stations and operative to convey the spherical object from the first orienting work station to the second orienting work station in such manner that the spherical object is rotated through the single-degree of freedom by 90 degrees; and

a second transposing mechanism pivotally mounted intermediate the second and third orienting work stations and operative to convey the spherical object from the second orienting work station to the third orienting work station is such manner that the spherical object is rotated through the single-degree of freedom by 90 degrees;

each of the first and second transposing mechanisms including a mechanical gripper.

9. The system of claim 7 wherein the 90 degrees single-degree of freedom rotation provided by the transposing means between the first and second and the second and third

orienting work stations are coplanar with the axes of rotation of the first, second, and third orienting work stations.

10. A system for automatically orienting a spherical object using a reference indicium on the spherical object, comprising:

first and second locating work stations each having an axis of rotation and operative to rotate the spherical object about the axis of rotation;

first, second, and third orienting work stations each having an axis of rotation and operative to rotate the spherical object about the axis of rotation through a predetermined angle of rotation so that the reference indicium at the third orienting work station has a predetermined final position and two-dimensional orientation wherein a target point on the spherical object, which has a predetermined spatial relationship to the reference indicium, is prepositioned for further processing;

transposing means for conveying the spherical object between the locating work stations and between the orienting work stations in such manner that the spherical object is rotated through a single-degree of freedom by 90 degrees each time the spherical object is conveyed between adjacent work stations, respectively;

an imaging system operative to generate an image of the spherical object at each of the first and second locating work stations as the spherical object is rotated about the axis of rotation of the first and second locating work stations, respectively; and

calculating means for processing the images of the spherical object generated at the first and second locating work stations to locate and identify a defined position and two-dimensional orientation of the reference indicium at the second locating work station and to determine the predetermined angles of rotation for the spherical object at the first, second, and third orienting work stations wherein the reference indicium is rotated from the defined position and two-dimensional orientation at the first orienting work station to the predetermined final position and two-dimensional orientation at the third orienting work station so that the target point is prepositioned for further processing.

11. The system of claim 10 wherein the second locating work station is equal to and functions as the first orienting work station.

12. The system of claim 10 wherein the imaging system comprises:

a first imaging means having an image axis perpendicular to the spherical object at the first locating work station;

a second imaging means having an image axis perpendicular to the spherical object at the second locating work station; and

wherein the first and second imaging means are operative to generate the image of the spherical object at the first and second locating work stations, respectively.

13. The system of claim 10 wherein the imaging system comprises:

a single imaging means;

a first set of mirrors aligned to capture the image of the spherical object at the first locating work station for the single imaging means;

a second set of mirrors aligned to capture the image of the spherical object at the second locating work station for the single imaging means;

wherein the single imaging means is operative, using the first and second set of aligned mirrors, to capture the image of the spherical object at the first and second locating work stations, respectively.

14. The system of claim 10 wherein the 90 degrees single-degree of freedom rotation provided by the transposing means between the locating work stations and the first, second, and third orienting work stations is coplanar with the axes of rotation of the first and second locating work stations and the first, second, and third orienting work stations.

15. The system of claim 11 wherein the transposing means comprises:

a first transposing mechanism pivotally mounted intermediate the first and second locating work stations and operative to convey the spherical object from the first locating work station to the second locating work station in such manner that the spherical object is rotated through the single-degree of freedom by 90 degrees; and

a second transposing mechanism pivotally mounted intermediate the first and second orienting work stations and operative to convey the spherical object from the first orienting

work station to the second orienting work station in such manner that the spherical object is rotated through the single-degree of freedom by 90 degrees; and

a third transposing mechanism pivotally mounted intermediate the second and third orienting work stations and operative to convey the spherical object from the second orienting work station to the third orienting work station in such manner that the spherical object is rotated through the single-degree of freedom by 90 degrees

16. The system of claim 15 wherein the 90 degrees single-degree of freedom rotation provided by the transposing means between the first and second locating work stations, the first and second orienting work stations, and the second and third orienting work stations is coplanar with the axes of rotation of the locating work stations and the orienting work stations.

17. The system of claim 15 wherein each of the first, second, and third transporting mechanisms includes a mechanical gripper dimensioned to mechanically engage the spherical object.

18. The system of claim 15 further comprising a motor means, and wherein each of the first, second, and third transport mechanisms is connected to a beam functionally connected to the motor means wherein the first, second, and third transport mechanisms are pivoted through the 90 degrees single-degree of freedom simultaneously.

19. The system of claim 10 wherein each of the first and second locating work stations and the first, second, and third orienting work stations comprises:

a bottom cup dimensioned to hold the spherical object;

means for engaging the spherical object in combination with the bottom cup; and

means for rotating the bottom cup with the spherical object engaged in combination therewith about the corresponding axis of rotation.

20. The system of claim 19 wherein the means for engaging the spherical object in combination with the bottom cup for rotation thereof about the corresponding axis of rotation comprises a vacuum.

21. The system of claim 19 wherein the means for engaging the spherical object in combination with the bottom cup for rotation thereof about the corresponding axis of rotation comprises a shaft having attached thereto an opposing upper cup and operative to move the opposing upper cup to physically engage the spherical object in combination with the bottom cup.

22. The system of claim 10 wherein

the calculating means is operative to process the image of the spherical object generated at the first locating work station to identify a coarse position and two-dimensional orientation of the reference indicium at the first locating work station and to determine an angle of rotation for the spherical object at the first locating work station; and wherein

the first locating work station is operative to rotate the spherical object through the predetermined angle wherein the reference indicium is moved from the defined coarse position and two-dimensional orientation to a second defined position and two-dimensional orientation at the first locating work station; and wherein

the transposing means is operative to convey the spherical object from the first locating work station to the second locating work station wherein the spherical object is rotated through a single-degree of freedom by 90 degrees such that the reference indicium of the spherical object is located at the defined position and two-dimensional orientation at the second locating work station.

23. The system of claim 10 wherein:

the first orienting work station is operative to rotate the spherical object through one of the predetermined angles of rotation such the reference indicium of the spherical object is moved from the defined position and two-dimensional orientation at the first orienting work station to a first reference position and two-dimensional orientation at the first orienting work station; and wherein

the transposing means is then operative to convey the spherical object from the first orienting work station to the second orienting work station so that the reference indicium is moved to a second reference position at the second orienting work station; and wherein

the second orienting work station is operative to rotate the spherical object through another of the predetermined angles of rotation such the reference indicium of the spherical object is moved from the second reference position and two-dimensional orientation at the second orienting work station to a third reference position and two-dimensional orientation at the second orienting work station; and wherein

the transposing means is then operative to convey the spherical object from the second orienting work station to the third orienting work station so that the reference indicium is moved to a fourth reference position at the third orienting work station; and wherein

the third orienting work station is operative to rotate the spherical object through yet another of the predetermined angles of rotation such the reference indicium of the spherical object is moved from the fourth reference position and two-dimensional orientation at the third orienting work station to the predetermined final reference position and two-dimensional orientation at the third orienting work station such that the target point on the spherical object is prepositioned for further processing.

24. The system of claim 23 wherein the one, another, and yet another predetermined angle of rotation implemented by the first, second, and third orienting work stations, respectively, comprise Euler angles of rotation .phi, .theta plus an additional 90 degrees, and .psi, respectively.

25. A method of automatically orienting a spherical object using a reference indicium on the spherical object so that a target point, which has a predetermined spatial relationship with the reference indicium, is prepositioned for further processing, comprising the steps of:

locating and defining a position and two-dimensional orientation of the reference indicium on the spherical object;

calculating, based on the defined position and two-dimensional orientation of the reference indicium, predetermined angles of rotation for the spherical object to move the

reference indicium from the defined position and two-dimensional orientation to the predetermined final position and two-dimensional orientation;

rotating the spherical object at a first orienting work station through one of the predetermined angles of rotation to move the reference indicium from the predefined position and two-dimensional orientation to a first reference position and orientation at the first orienting work station;

conveying the spherical object from the first orienting work station to a second orienting work station in a manner such that the spherical object is rotated through a single-degree of freedom by 90 degrees wherein the reference indicium is at a second reference position and two-dimensional orientation at the second orienting work station;

rotating the spherical object at the second orienting work station through another of the predetermined angles of rotation to move the reference indicium from the second reference position and two-dimensional orientation to a third reference position and two-dimensional orientation at the second orienting work station;

conveying the spherical object from the second orienting work station to a third orienting work station in a manner such that the spherical object is rotated through a single-degree of freedom by 90 degrees wherein the reference indicium is at a fourth reference position and two-dimensional orientation at the third orienting work station; and

rotating the spherical object at the third orienting work station through yet another of the predetermined angles of rotation to move the reference indicium from the fourth reference position and two-dimensional orientation to the predetermined final position and two-dimensional orientation at the third orienting work station wherein the target point is prepositioned for further processing.

26. The method of claim 25 wherein the step of locating the defined position and two-dimensional orientation of the reference indicium on the spherical object comprises the steps of:

providing the spherical object having a random position and two-dimensional orientation of the reference indicium at a first locating work station;

imaging the spherical object at the first locating work station;

determining a coarse position and two-dimensional orientation of the reference indicium using the generated image;

calculating an angle of rotation for the spherical object at the first locating work station using the generated image;

rotating the spherical object through the calculated angle of rotation to move the reference indicium from the coarse position and two-dimensional orientation to a second position and two-dimensional orientation at the first locating work station;

conveying the spherical object from the first locating work station to a second locating work station in a manner such that the spherical object is rotated through a single-degree of freedom by 90 degrees wherein the reference indicium is at the defined position and orientation at the second locating work station;

imaging the spherical object at the second locating work station; and

locating and defining the defined position and two-dimensional orientation of the reference indicium of the spherical object at the second locating work station using the generated image.

27. A system for imaging the surface of a spherical object, comprising:

a first work station having an axis of rotation and operative to rotate the spherical object about the axis of rotation, and wherein a plane of the spherical object perpendicular to the axis of rotation is defined as the rotational plane of the spherical object at the first work station;

a second work station having an axis of rotation and operative to rotate the spherical object about the axis of rotation, and wherein a plane of the spherical object perpendicular to the axis of rotation is defined as the rotational plane of the spherical object at the second work station;

transposing means for conveying the spherical object from the first work station to the second work station in such manner that the spherical object is rotated through a single degree of freedom by 90 degrees wherein the rotational plane of the spherical object at the first working station is rotated through an angle of 90 degrees such that the rotational plane defined by the spherical object at the first work station is perpendicular to the rotational plane of the spherical object at the second work station; and

an imaging system positioned and operative to generate an image of the surface of the spherical object at each of the first and second work stations; and wherein

the imaging system is operative to generate a first image of the surface of the spherical object as the spherical object is rotated through at least one complete revolution about the axis of rotation of the first work station; and wherein

the imaging system is operative to generate a second image of the surface of the spherical object as the spherical object is rotated through at least one complete revolution about the axis of rotation of the second work station.

28. The system of claim 27 wherein the imaging system comprises:

a first imaging means having an image axis perpendicular to the spherical object at the first work station and operative to generate the first image of the surface of the spherical object; and

a second imaging means having an image axis perpendicular to the spherical object at the second work station and operative to generate the second image of the surface of the spherical object.

29. The system of claim 28 wherein the first and second imaging means are line sensor cameras.

30. ~~29.~~ The system of claim 27 wherein the imaging system comprises:

a single imaging means;

a first set of mirrors aligned to capture the first image of the spherical object at the first work station for the single imaging means; and

a second set of mirrors aligned to capture the second image of the spherical object at the second work station for the single imaging means.

31. ~~30.~~ The system of claim 29 wherein the single imaging means is a line sensor camera.

32. ~~31.~~ The system of claim 27 wherein the transposing means comprises

a transposing mechanism pivotally mounted intermediate the first and second work stations for conveying the spherical object from the first work station to the second work station, the transposing mechanism including a mechanical gripper that is dimensioned and operative to hold the spherical object to conveyance thereof from the first work station to the second work station.

32. The system of claim 27 further comprising:

means for converting the first and second images of the surface of the spherical object to a virtual image;

electronically-stored reference data representing a standard graphical configuration of the surface of the spherical object; and

means for comparing the virtual image of the first and second images of the surface of the spherical object to the electronically-stored reference data representing the standard graphical configuration of the surface of the spherical object to detect any discrepancies therebetween.